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ENERGY SECURITY: CONCEPTUALISING A LOW-CARBON ENERGY MIX FOR AIRPORTS IN SOUTH AFRICA

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Abstract

Energy security is found in diversification of energy sources drawing power from an energy mix while moving away from carbon intensive energy sources causing climate change. This is a unique challenge for developing countries. This paper presents the journey of conceptualising a low-carbon energy mix for nine airports in South Africa.

Keywords: Airports in South Africa low carbon energy mix, baseload energy, fluctuating energy loads, airports natural resources, theoretical energy potential, available energy potential, real energy generation potential.

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Original Article

INTRODUCTION

Airports are a key infrastructure in the economy of a country. At the heart of their proper functioning and security is the availability of reliable sources of energy. The current energy supply challenges facing Eskom threaten the present and future of airports and their proper functioning and security. Relying on Eskom alone for electricity to run airports is not a sustainable solution. Coupled with this is the climate change mitigation imperative that is part of the business's environmental objective. Airports Company South Africa (ACSA) is South Africa's airport authority and owns and operates nine airports, namely, O R Tambo International Airport (ORTIA) (Kempton Park, Gauteng), Cape Town International Airport (CTIA) (Western Cape), King Shaka International Airport (KSIA) (Durban, KwaZulu-Natal), Port Elizabeth International Airport (Eastern Cape) (PEIA), East London Airport (Eastern Cape) (EL), Bram Fischer International Airport (Bloemfontein, Free State) (BFIA), George Airport (Eastern Cape) (GG), Upington International Airport (Northern Cape) (UPIA) and Kimberley Airport (Northern Cape) (KIM). From [1], the three principles for achieving energy security in developing countries are given as follows:

Principle 1: Ascertain the energy generation potential of the site, i.e., what is the:

(a) Theoretical energy potential of the site as found in Equation (1):

$$Total\ Theoretical\ Energy\ Potential = \sum Renewable\ energy\ potential + \sum Energy\ potential\ from\ human\ and\ industrial\ activity + \sum Energy\ potential\ from\ alternative\ less\ carbon\ intensive\ energy\ sources$$ …………….. Equation (1)

(b) Available energy potential by applying the commercially available technologies as found in Equation (2):

$$Total\ Available\ Energy\ Potential = \sum(Renewable\ energy\ potential \times CF) + \sum(Energy\ potential\ from\ human\ and\ industrial\ activity \times CF) + \sum(Energy\ potential\ from\ alternative\ less\ carbon\ intensive\ energy\ sources \times CF)$$ Eq

(2)

(c) Real energy generation potential considering the spatial and other demands required for energy generation, as found in Equation (3):

$$Total\ Real\ Energy\ Generation\ Potential = \sum(Total\ real\ renewable\ energy\ generation\ potential \times area\ available) + \sum(Total\ real\ energy\ generation\ potential\ from\ human\ and\ industrial\ activity \times area\ available) + \sum(Total\ real\ energy\ generation\ potential\ from\ alternative\ less\ carbon\ intensive\ energy\ sources \times area\ available)$$

……… Eq(3)

Principle 2: Ascertain the site's energy needs in the present and the future (short, medium and long term) considering the following:

(a) Type of energy required and their quantities,

(b) Baseload energy requirements,

(c) Fluctuating load energy requirements and their timing; and

(d) Strategies for energy reduction, conservation, load levelling and load shifting and their timing.

Principle 3: Match the energy sources available to the energy needs of the site considering:

(a) Energy efficiency and load dynamics,

(b) Commercial technologies available and their impact, risks and implications for the business,

(c) Feasibility to install, operate and maintain and

(d) Business imperatives and strategies (less carbon emissions, insource/outsource strategies, capacity building, corporate social responsibility).

The principles for energy security enable one to be aware of the full energy generation potential of the site. This approach is ideal for a strategy that wants to not only generate energy for own use, but for generating commercial revenue. It is also the approach advised to sustainably reach and maintain energy security in developing countries. The strategy that the energy mix for the airports sought to fulfil when it was formulated in FY 2018/2019 (1 April 2018 to 31 March 2019) using data for the period 1 April 2017 to 31 March 2018 was to reach carbon neutrality in electricity consumption. This paper uses these three principles to conceptualise the energy mix for nine airports in South Africa owned and operated by ACSA.

Energy generation potential of airports in South Africa

The application of Principle 1 gives the theoretical energy potential considering the natural resources available in the geographical region, the available energy potential considering the efficiency of the conversion technologies, and the real energy generation potential considering the spatial and other constraints of the site. Table 1 gives the approximate land footprint of the airports, their occupied land footprint and their occupied land footprint at full development which is at around the year 2050.

Table 1: Estimated land footprint of airports in South Africa

Airport	Onsite facilities as at 2018	Total land footprint	Current occupied land footprint	Final occupied land footprint at full capacity
O R Tambo International Airport	Passenger terminal buildings and passenger boarding bridges including commercial and retail stores, restaurants, baggage handling facilities, waste sorting areas, sewage sumps, water storage tanks, HVAC plants. Aprons (parking bays for aircraft), air traffic control tower, radar towers, cargo terminal building, aircraft hangers with maintenance and repairs, firefighting facilities, jet A1 fuel storage and hydrant network, runways, taxiways, three hotels, car rental facilities and wash bays, car parking lots, office buildings, warehouses, cold storage rooms, maintenance storage and stock rooms, bus staging areas, vehicle fuelling stations.	19.84 km^2 (Estimated using Google Maps, including runways, taxiways and vacant land)	8.31 km^2 (Estimated using Google Maps, including runways and taxiways)	19.84 km^2 (Assumed full development of current land footprint; future land acquisitions not accounted for)
Cape Town International Airport	Passenger terminal buildings and passenger boarding bridges including commercial and retail stores, restaurants, baggage handling facilities, waste sorting areas, sewage sumps, water storage tanks, HVAC plants. Aprons (parking bays for aircraft), air traffic control tower, radar towers, cargo terminal building, aircraft hangers with maintenance and repairs, firefighting facilities, jet A1 fuel storage and hydrant network, runways, taxiways, three hotels, car rental facilities and wash bays, car parking lots, office buildings, warehouses, cold storage rooms, maintenance storage and stock rooms, bus staging areas, vehicle fuelling stations.	9.76 km^2 (Estimated using Google Maps, including runways, taxiways and vacant land)	5.90 km^2 (Estimated using Google Maps, including runways and taxiways)	9.76 km^2 (Assumed full development of current land footprint; future land acquisitions not accounted for)
King Shaka International Airport	Passenger terminal buildings and passenger boarding bridges including commercial and retail stores, restaurants, baggage handling facilities, waste sorting areas, sewage sumps, water storage tanks, HVAC plants. Aprons (parking bays for aircraft), air traffic control tower, radar towers, cargo terminal building, aircraft hangers with maintenance and repairs, firefighting facilities, jet A1 fuel storage and hydrant network, runways, taxiways, three hotels, car rental facilities and wash bays, car parking lots, office buildings, warehouses, cold storage rooms, maintenance storage and stock rooms, bus staging areas, vehicle fuelling stations.	7.11 km^2 (Estimated using Google Maps, including runways, taxiways and vacant land)	3.26 km^2 (Estimated using Google Maps, including runways and taxiways)	7.11 km^2 (Assumed full development of current land footprint; future land acquisitions not accounted for)
Port Elizabeth International Airport	Passenger terminal buildings, retail stores, restaurants, luggage conveyor belts, waste sortation area, water storage tanks, HVAC plant. Aprons (parking bays for aircraft), air traffic control tower, radar tower, firefighting facilities, jet A1 fuel storage and hydrant network, runways, taxiways, car rental facilities and wash bays, car parking lots, office buildings.	3.79 km^2 (Estimated using Google Maps, including runways, taxiways and vacant land)	1.26 km^2 (Estimated using Google Maps, including runways and taxiways)	2.90 km^2 (Assumed development of current land footprint; future land acquisitions not accounted for)
East London Airport	Passenger terminal buildings including restaurants, baggage conveyor belts, waste	1.69 km^2 (Estimated	0.84 km^2 (Estimated	1.16 km^2 (Assumed

	sortation area, office areas, HVAC plant. Aprons (parking bays for aircraft), air traffic control tower, radar tower, firefighting facilities, jet A1 fuel storage tank, runways, taxiways, car rental facilities and wash bays, car parking lots, office building	using Google Maps, including runways, taxiways and vacant land)	using Google Maps, including runways and taxiways)	development of current land footprint; future land acquisitions not accounted for)
Bram Fischer International Airport	Passenger terminal buildings including restaurants, baggage conveyor belts, waste sortation areas, water storage tanks, HVAC plant. Aprons (parking bays for aircraft), air traffic control tower, radar tower, firefighting facilities, jet A1 fuel storage and hydrant network, runways, taxiways, hospital, car rental facilities and wash bays, car parking lot, office building	7.71 km^2 (Estimated using Google Maps, including runways, taxiways and vacant land)	1.87 km^2 (Estimated using Google Maps, including runways and taxiways)	2.97 km^2 (Assumed development of current land footprint; future land acquisitions not accounted for)
George Airport	Passenger terminal buildings including restaurants, baggage conveyor belts, waste sortation area, HVAC plant. Aprons (parking bays for aircraft), Air traffic control tower, radar tower, firefighting facilities, jet A1 fuel storage tank, runways, taxiways, car rental facilities and wash bays, car parking lots, office buildings.	2.64 km^2 (Estimated using Google Maps, including runways, taxiways and vacant land)	1.02 km^2 (Estimated using Google Maps, including runways and taxiways)	2.18 km^2 (Assumed development of current land footprint; future land acquisitions not accounted for)
Upington International Airport	Passenger terminal buildings including restaurants, baggage conveyor belt and carousel, water storage tank, HVAC packaged plant. Aprons (parking bays for aircraft), air traffic control tower, radar tower, firefighting facilities, jet A1 fuel storage tank, runways, taxiways, car rental facilities and wash bays, car parking lot, office buildings.	8.07 km^2 (Estimated using Google Maps, including runways, taxiways and vacant land)	3.75 km^2 (Estimated using Google Maps, including runways and taxiways)	6.14 km^2 (Assumed development of current land footprint; future land acquisitions not accounted for)
Kimberley Airport	Passenger terminal buildings including a cafe, baggage conveyor belt and carousel, HVAC decentralised units. Aprons (parking bays for aircraft), air traffic control tower, radar tower, firefighting facilities, jet A1 fuel storage tank, runways, taxiways, car rental facilities and wash bays, car parking lot, office buildings.	5.17 km^2 (Estimated using Google Maps, including runways, taxiways and vacant land)	1.98 km^2 (Estimated using Google Maps, including runways and taxiways)	2.06 km^2 (Assumed development of current land footprint; future land acquisitions not accounted for)

Table 2 contains some of the indicators of the theoretical energy generation potential, the available energy generation potential, and the real energy generation potential of the airport sites. Some energy sources will require further investigation such as natural gas, waste to energy and geothermal heat sinks as the quantity of natural gas that is available to be secured has to be confirmed, the quality of the waste and energy value must be tested in a lab, and the soil conditions must be tested. Wind energy uses vertical axis wind turbines (VAWT) at a height of 12 m.

Table 2: Theoretical energy generation potential, available energy generation potential and real energy generation potential of the airport sites

Airport	Type of energy	Annual theoretical energy generation potential	Annual available energy generation potential	Annual real energy generation potential	Notes
ORTIA	Solar to electricity	2000 kWh/m^2 [2]	528 kWh/m^2 (Capacity factor of 26.4 %)	**Full site (FS):** 10 475.52 GWh **Unoccupied land (UL):** 6 598.725 GWh **Unoccupied land at full development (UL@FD):** 0	ORTIA natural gas availability requires investigation; waste to energy will require specific lab tests to determine the calorific value.
	Solar to thermal energy	2250 kWh/m^2 [3]	832.5 kWh/m^2 (Capacity factor of 37 %)	**FS:** 16 516.80 GWh **UL:** 9 598.725 GWh **UL@FD:** 0	
CTIA	Solar to electricity	1900 kWh/m^2 [2]	501.6 kWh/m^2 (Capacity factor 26.4 %)	**FS:** 4 895.616 GWh **UL:** 1 936.176 GWh **UL@FD:** 0	CTIA natural gas availability requires investigation; geothermal resources require in depth investigation into soil conditions for heat exchange, and waste to energy requires specific lab tests to determine calorific value.
	Solar to thermal energy	2100 kWh/m^2 [3]	777 kWh/m^2 (Capacity factor 37 %)	**FS:** 7 583.52 GWh **UL:** 2 999.22 GWh **UL@FD:** 0	
	Wind energy to electricity	112 kWh/m^2 (12 m height)	39.4 kWh/m^2 (Capacity factor 35.2 %)	**FS:** 384.778 GWh **UL:** 152.177 GWh **UL@FD:** 0	
KSIA	Solar to electricity	1500 kWh/m^2 [2]	396 kWh/m^2 (Capacity factor 26.4 %)	**FS:** 2 815.56 GWh **UL:** 1 524.6 GWh **UL@FD:** 0	KSIA natural gas availability requires investigation, and waste to energy requires specific lab tests to determine calorific value.
	Solar to thermal energy	1500 kWh/m^2 [3]	555 kWh/m^2 (Capacity factor 37 %)	**FS:** 3 946.05 GWh **UL:** 2 136.75 GWh **UL@FD:** 0	
PEIA	Solar to electricity	1750 kWh/m^2 [2]	462 kWh/m^2 (Capacity factor 26.4 %)	**FS:** 1 750.98 GWh **UL:** 1 168.86 GWh **UL@FD:** 411.18 GWh	Wind energy using vertical axis wind turbines takes into account the spacing and allows for a maximum height of 12 m. The waste volumes are not sufficient to generate energy from.
	Solar to thermal energy	1700 kWh/m^2 [3]	629 kWh/m^2 (Capacity factor 37 %)	**FS:** 2 383.91 GWh **UL:** 1 591.37 GWh **UL@FD:** 559.81 GWh	
	Wind energy	112 kWh/m^2	39.4 kWh/m^2 (Capacity factor 35.2 %)	**FS:** 149.42 GWh **UL:** 99.74 GWh **UL@FD:** 35.09 GWh	
EL	Solar to electricity	1650 kWh/m^2 [2]	435.6 kWh/m^2 (Capacity factor 26.4 %)	**FS:** 736.164 GWh **UL:** 370.26 GWh **UL@FD:** 230.87 GWh	Wind energy using vertical axis wind turbines takes into account the spacing and allows for a maximum height of 12 m. The waste volumes
	Solar to thermal energy	1600 kWh/m^2 [3]	592 kWh/m^2 (Capacity factor 37 %)	**FS:** 1 000.48 GWh **UL:** 503.2 GWh **UL@FD:** 313.76 GWh	
	Wind energy	112 kWh/m^2	39.4 kWh/m^2 (Capacity factor 35.2 %)	**FS:** 66.627 GWh **UL:** 33.51 GWh	

				UL@FD: 20.89 GWh	are not sufficient to generate energy from.
BFIA	Solar to electricity	2100 kWh/m^2 [2]	554.4 kWh/m^2 (Capacity factor 26.4 %)	**FS:** 4 274.42 GWh **UL:** 3 237.7 GWh **UL@FD:** 2 627.856 GWh	The waste volumes are not sufficient to generate energy from.
	Solar to thermal energy	2600 kWh/m^2 [3]	962 kWh/m^2 (Capacity factor 37 %)	**FS:** 7 417.02 GWh **UL:** 5 618.08 GWh **UL@FD:** 4 559.88 GWh	
GG	Solar to electricity	1550 kWh/m^2 [2]	409.2 kWh/m^2 (Capacity factor 26.4 %)	**FS:** 1 080.288 GWh **UL:** 662.904 GWh **UL@FD:** 188.23 GWh	Wind energy using vertical axis wind turbines takes into account the spacing and allows for a maximum height of 12 m. The waste volumes are not sufficient to generate energy from.
	Solar to thermal energy	1700 kWh/m^2 [3]	629 kWh/m^2 (Capacity factor 37 %)	**FS:** 1 660.56 GWh **UL:** 1 018.98 GWh **UL@FD:** 289.34 GWh	
	Wind energy	112 kWh/m^2	39.4 kWh/m^2 (Capacity factor 35.2 %)	**FS:** 104.079 GWh **UL:** 63.867 GWh **UL@FD:** 18.135 GWh	
UPIA	Solar to electricity	2300 kWh/m^2 [2]	607.2 kWh/m^2 (Capacity factor 26.4 %)	**FS:** 4 900.104 GWh **UL:** 2 623.104 GWh **UL@FD:** 1 171.896 GWh	The waste volumes are not sufficient to generate energy from.
	Solar to thermal energy	3200 kWh/m^2 [3]	1184 kWh/m^2 (Capacity factor 37 %)	**FS:** 9 554.88 GWh **UL:** 5 114.88 GWh **UL@FD:** 2 285.12 GWh	
KIM	Solar to electricity	2100 kWh/m^2 [2]	554.4 kWh/m^2 (Capacity factor 26.4 %)	**FS:** 2 866.25 GWh **UL:** 1 768.536 GWh **UL@FD:** 1 724.184 GWh	The waste volumes are not sufficient to generate energy from.
	Solar to thermal energy	2900 kWh/m^2 [3]	1073 kWh/m^2 (Capacity factor 37 %)	**FS:** 5 547.41 GWh **UL:** 3 422.87 GWh **UL@FD:** 3 337.03 GWh	

The information contained in Table 2 is key in assessing the available resources whenever there is an energy demand to satisfy, or if an organisation wants to commercialise the site's energy resources. ACSA's strategy when undertaking an energy mix for its airports is to reach carbon neutrality in electricity consumption while ensuring that the energy mix implemented is financially feasible and suitable to the airports' operating environment.

Airports' Energy Demand

The energy consumption of ACSA's nine airports vary significantly relative to each other. The energy consumption of ACSA's nine airports together with the resulting carbon footprint are given in Figure 1. Each airports' contribution to the total carbon footprint resulting from energy consumption of all nine airports are given in Figure 2.

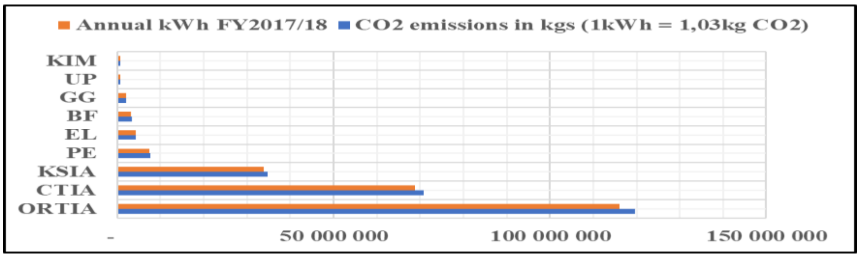


Figure 1: Electrical energy consumption and resulting carbon emissions of ACSA's airports for the period 1 April 2017 to 31 March 2018

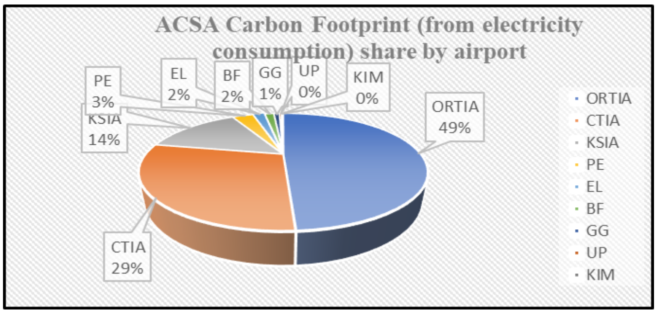
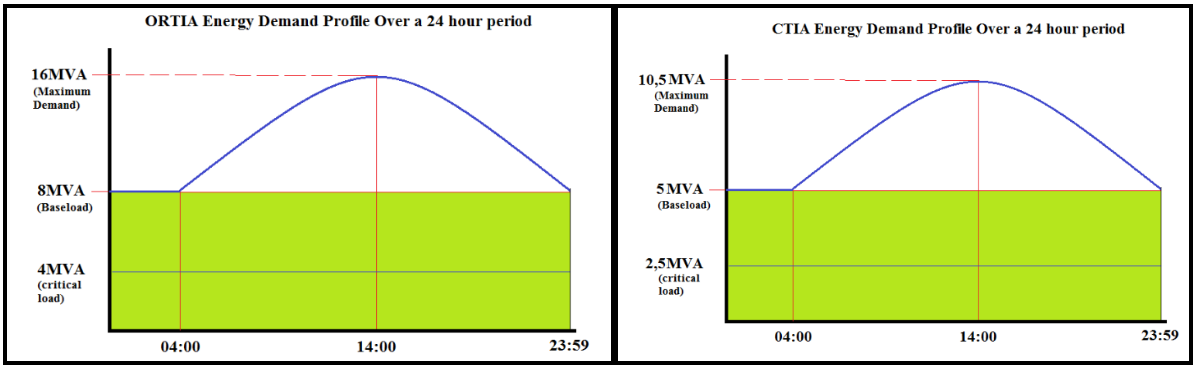


Figure 2: ACSA airports' carbon footprints share from electricity consumption

ORTIA accounts for about half of the electricity consumption and carbon footprint of the group of nine airports, followed by CTIA at 29 % and KSIA at 14 %, together, these three airports account for 93 % of the energy consumption of the group. The electricity consumption of the airports also varies according to their operational hours and size of the development. Fig. 3 gives the estimated electricity consumption profile of the nine airports, showing their baseload, fluctuating load and critical load portions forming part of the baseload. GG, UPIA and KIM airports existing solar PV plants are shown in their electricity consumption profile as the dotted portion of their peak loads.

An airport's significant energy users are lighting and air conditioning [4], so these are the main contributors to the shaping of an airport's electricity demand profile. The lighting load of an airport constitutes much of the baseload, including the critical load as runways and taxiways which have to be lit according to legislation almost all the time. Air conditioning is needed for the comfort of the buildings and for keeping electronic equipment at a specific operating temperature. This causes the peak electricity load of airports. Lighting and air conditioning loads are supplied from the national electricity grid. Peak loads at GG, UPIA and KIM airports are supplied with electricity from their solar PV plants, as indicated in Fig. 3.



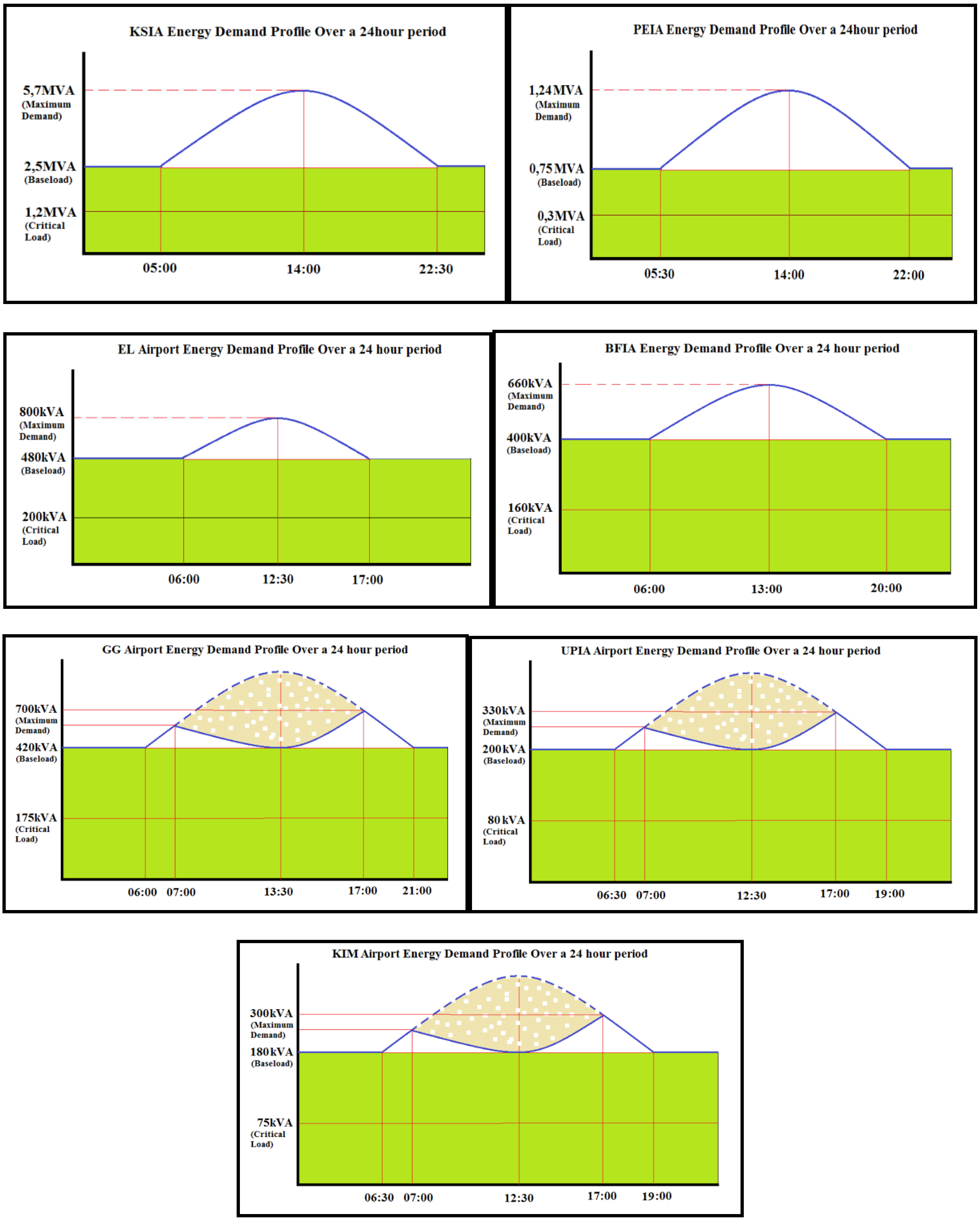


Figure 3: Load dynamics for ACSA's airports in South Africa

Conceptual roadmaps for achieving a low carbon energy mix

Reducing and where possible eliminating energy wastage is crucial to cost effectiveness in the journey of reducing carbon emissions. The energy reduction projects to reduce electricity demand through energy efficiency, energy conservation and through supplying an energy demand from a different source are given in Table 3.

Table 3: Planning for Grid Electricity Reduction at Airports

Significant energy user	Description and notes	Projects to be considered for investigation	Notes
Lighting	Lighting share being around 50 % to 60 % of each airport's total energy consumption	This can be reduced by at least 15 % (up to 30 %) through adoption of LED lighting	Investigate the adoption of LED lighting for each airport including feasibility
		Lighting control can give a further 10 % through the adoption of occupancy sensors, timers, photocells and dimming functions installed and programmed.	Investigate the adoption of lighting control for each area where lighting demand varies throughout the day.
Heating, ventilation and air-conditioning	This share varies from 20 % to 30 % of airport's total energy consumption	Air conditioning systems to be re-designed with time by additions and refurbishments to ensure a smooth notified maximum demand curve through the application of energy reduction, load levelling techniques and load shifting techniques. Projects include: - Heat pipe dehumidification - Re-use of condensate as make-up water and as an aid in achieving the temperature required to cool chillers - Re-use of condenser water in a heat exchanger as a pre-heater to the geysers or any other process requiring a heated fluid - Active chilled water set-point control, variable speed drives, air economising, fresh air demand control - Ice storage or chilled water storage	Investigations into the feasibility and technical suitability of implementing these projects at ORTIA, CTIA, KSIA confirming financial viability and technical suitability.
		Reduction of cooling/heating demand projects include: - Heat resistant coating on roof/solar thermal roof/green roof - Solar thermal walls OR heat deflection facades - Building envelope and fenestration projects	Investigations to be done for all airports confirming financial feasibility and application.
		Greenest air conditioning system with existing technology made up of: -Absorption chillers providing space heating and cooling -Powered by solar thermal energy -Using water as refrigerant, lithium bromide as absorbent -Cooling towers to be replaced by geothermal heat sinks	Investigations to be done for PEIA, EL, BFIA and GG, confirming technical suitability and financial viability. Geothermal heat sinks instead of evaporative cooling towers should also be investigated for ORTIA, CTIA and KSIA.

In the journey of investigating the above projects for implementation at the airports, some airports may not be technically suited for certain projects, or a project may not apply to the airport, and thus financial feasibility will not need to follow. Once energy reduction projects have been planned for, reducing carbon emissions further will require the adoption of less carbon intensive energy sources for electricity generation. The adoption of a low carbon energy mix is not common practice in South Africa and alternative energy sources such as renewable energy technologies and their methods of operation are unfamiliar, even though they are proven to work in other countries.

To ensure that the airport sites and business operations adjust, become familiar and confident with alternative energy technologies, a phased approach to achieve carbon neutrality in electricity consumption is proposed. Table 4 gives the phased approach to carbon neutrality in electricity consumption at the nine airports in South Africa.

Table 4: Phases to Carbon Neutrality in electricity Consumption at the nine airports in South Africa

Phase	Description of phase
Preliminary and ongoing during the implementation of the energy mix	1. Changing of lighting technology to LED. 2. Lighting control to be achieved for all areas. 3. Implementation of initiatives to reduce HVAC chiller load such as convective boundaries, thermal resistant coatings on walls and roof, heat pipe dehumidification in air handling units and other passive cooling techniques. 4. Refurbishment programmes to ensure adoption of energy efficient pumps, motors, controls and processes.
One (From year 2018 to year 2024)	1. The low carbon energy mix will be designed to supply the airports' maximum electricity demands (kVA or MVA) as of the year 2018. 2. For ORTIA, CTIA and KSIA, the airport's critical load will be supplied (or backed up) through the national electricity grid to ensure minimal interruptions to airport operations during the initial stages of the operation of the natural gas trigeneration plants (electricity, thermal energy and cooling) which will be designed to have the capacity to support the airports' 2018 electricity demand. 3. The existing solar PV plants at GG, UPIA and KIM airports will be provided with solar energy storage to ensure that all the electricity generated by the plant is being utilised by the airports. This is also the approach with the planned solar PV plants for PEIA, EL and BFIA. 4. Increase in electricity consumption (kWhs) during this period in phase one will either be offset by a decrease in 2018 electricity consumption (baseline) through energy reduction projects or absorbed by the current energy mix as this is designed to supply the airports maximum demand (kVA or MVA).
Two (From year 2024 to 2027)	1. Focus of investigation for implementation will be the business risk to airport operations of supplying the airports' critical electrical load and other new loads from the natural gas trigeneration plants for ORTIA, CTIA and KSIA by either expanding these plants, expanding the energy mix for these airports, or considering forms of energy storage to run the natural gas trigeneration plant in phase one at full capacity. 2. For additional loads from this point to ensure that the airports' energy consumption is energy efficient and as low in carbon emissions as possible. the adoption of green star rated buildings will be required for new infrastructure with the emphasis being on designing buildings to be carbon neutral in terms of energy consumption. 3. A smart electrical grid will be implemented to coordinate various energy supply sources for uninterrupted service to airport operations and to ensure a constant energy demand profile.
Three (From year 2027 and beyond)	1. Focus of implementation will be on further reduction in carbon emissions from the natural gas engines towards carbon neutrality by considering the following options and combinations thereof: - Change of fuel type of the operating natural gas trigeneration plants - Process innovation to capture and sequester the carbon emissions - Technology change of combustion engines to ensure zero carbon emissions 2. Unavoidable carbon emissions for the purposes of ensuring reliable service to airport operations within financial feasibility will be offset by initiatives that allow for ACSA to either purchase carbon credits or implement carbon offsetting solar PV and wind generation plants either on their vacant land or for a community or school as a social development project towards corporate social investment to reach carbon neutrality in electricity consumption.

Figure 4 to Figure 12 with an accompanying table (Table 5 to Table 13) give the conceptual journey of each airport to carbon neutrality in electricity consumption.

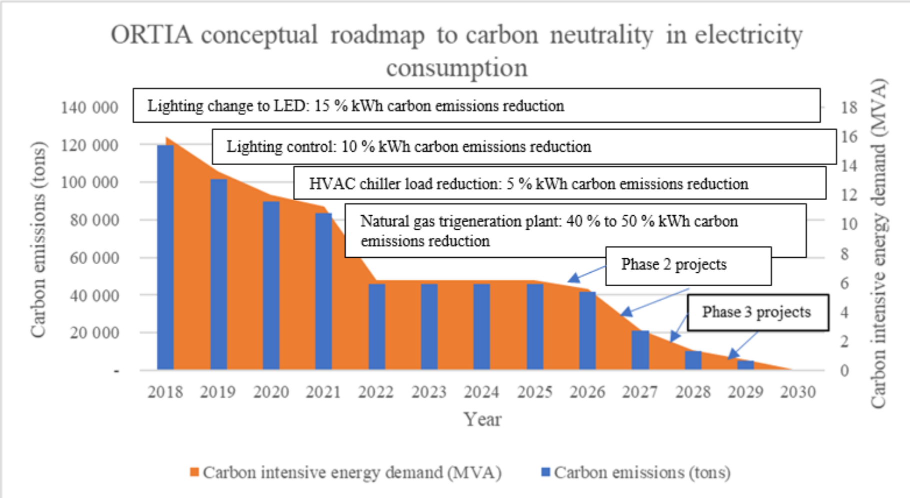


Figure 4: OR Tambo International Airport's Conceptual Roadmap to Carbon Neutrality in Electricity Consumption

Table 5: Projects for ORTIA's energy mix conceptual roadmap towards carbon neutrality in electricity consumption

Phase	Energy sources and projects	Requirements prior to implementation	Notes
Preliminary	1. Lighting change to LED. 2. Lighting control: occupancy sensors, BMS (building management system) control, dimming functions. 3. HVAC chiller load reduction: convective boundaries - double glazing or low emissivity glass, thermal deflection innovation (Heat deflective paint on roof/insulation), wind lobbies, etc. 4. Geyser sleeve technology [Too small to count as a step change on graph]	Financial feasibility and technical assessment (technoeconomic studies)	Wind lobbies were not ideal for ORTIA's terminal building layout, so this was not taken to the financial feasibility stage.
One	1. Natural gas trigeneration plants producing electricity through the combustion of natural gas and recovering the waste heat for thermal energy uses such as hot water and powering absorption chillers. 2. Waste to energy via anaerobic digestion producing a biogas that can be combusted for electricity generation.	1. Technoeconomic assessment is required as well as a confirmed feasibility based on the engineering design before a financial investment decision is made and security of fuel gas supply. 2. Waste streams are to be tested for their calorific value and a full technoeconomic assessment should follow	- Due to ORTIA's commercial expansion plans, using solar energy for electricity consumption is spatially not advisable and the high baseload will make energy storage a very costly endeavour. - Incinerating dry waste may not be feasible as a fuel source due to its variability in calorific value and carbon emissions. - Using geothermal

			energy as a heat sink involves costly preliminary groundwork such as soil testing. It would be better to undertake a pilot plant at a better suited airport prior to investment for a feasibility study.
Two	1. Using the natural gas trigeneration plant or using the anaerobic digestion plant from phase one to supply the critical load of the airport and for additional electrical loads. 2. New infrastructure to adopt a green star rating targeting carbon neutrality in electricity consumption. 3. Smart electrical grid to be adopted to coordinate energy sources ensuring an uninterrupted power supply.	1. Confirmation of availability of additional natural gas to supply the airport's critical electrical load, space constraints for plant operation, suitability to support airport critical electrical load, integration requirements, economic feasibility. 2. Consider the feasibility of incorporating renewable energy such as solar PV and solar thermal for new infrastructure. 3. An in-depth investigation into the airport's real time energy consumption to determine energy storage requirements, load-levelling and load shifting techniques for implementation, as well as load curtailment to ensure a feasible electrical integration and smart grid design.	- Adoption of other energy sources such as decentralised packaged waste to energy plants, or rooftop solar PV plants, serving a specific new infrastructure must take into account the operational and maintenance cost of these plants, including the environmental impact.
Three	1. Fuel change from natural gas to a fuel with lower carbon footprint such as LPG or biogas. 2. Process innovation to sequester carbon emissions. 3. Technology change towards no carbon emissions. 4. Carbon offsetting plants or purchasing of carbon credits to reach carbon neutrality in electricity consumption.	1. Investigation into possible alternative fuels that are less carbon intense than natural gas and selecting the combustion engine technology that allows multiple fuel type intake is key for this to work cost effectively. 2. Sequestering carbon will require in-depth environmental and	- Technology change might not be possible if there are no technology improvements commercially available. - Carbon sequestration might rely on a range of factors, both environmental, site and business related. - The better choice to invest effort in

		financial investigation. 3. Technology change will be dependent on the commercial market evolution, and this must be actively monitored. 4. A feasibility study must be undertaken on carbon offsetting plants versus purchasing carbon credits. An integrated view must be considered.	investigation is a dual fuel combustion engine and carbon offsetting plants on vacant land at regional airports as a commercial venture (independent power producer) or undertake a corporate social investment project installing a solar PV or wind plant at a facility and claim the carbon credits.

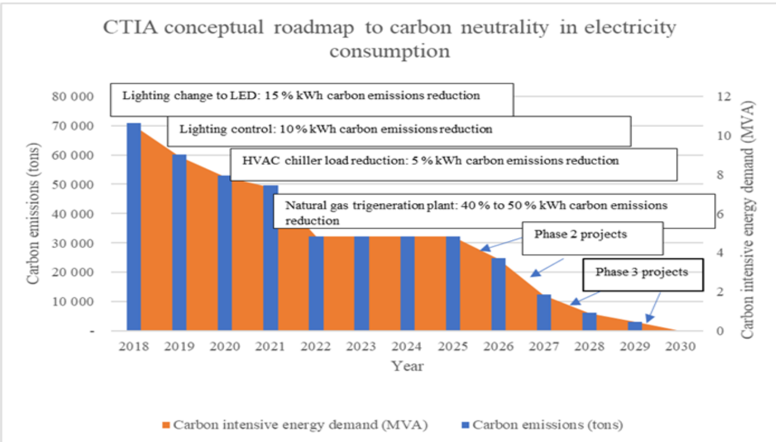


Figure 5: Cape Town International Airport's conceptual roadmap to carbon neutrality in electricity consumption

Table 6: Projects for CTIA's energy mix conceptual roadmap towards carbon neutrality in electricity consumption

Phase	Energy sources and projects	Requirements prior to implementation	Notes
Preliminary	1. Lighting change to LED. 2. Lighting control: occupancy sensors, BMS (building management system) control, dimming functions. 3. HVAC chiller load reduction: convective boundaries - double glazing or low emissivity glass, thermal deflection innovation (heat deflective paint on roof/insulation), wind lobbies, etc. 4. Geyser sleeve technology [Too small to count as a step change on graph].	Financial feasibility and technical assessment (technoeconomic studies).	Wind lobbies were not ideal for CTIA's terminal building layout, so was not taken to the financial feasibility stage.

One	1. Natural gas trigeneration plants producing electricity through combustion of natural gas and recovering the waste heat for thermal energy uses such as hot water and powering absorption chillers. 2. Waste to energy via anaerobic digestion producing a biogas that can be combusted for electricity generation. 3. Wind energy generating electricity via vertical axis wind turbines. 4. Geothermal heat sinks to replace evaporative cooling towers.	1. Technoeconomic assessment is required as well as a confirmed feasibility study based on the engineering design before a financial investment decision is made and security of fuel gas supply. 2. Waste streams are to be tested for their calorific value and a full technoeconomic assessment should follow. 3. Securing of a suitable installation site with the necessary approvals from Air Traffic Navigational Services (ATNS) and South African Civil Aviation Authority (SACAA), followed by a full technoeconomic assessment. 4. Perform technoeconomic assessment and install a test geothermal heat sink loop similar to the one installed at Hotel Verde, just 2 km from the CTIA terminal building to become familiar with the operational cycles for mass roll out.	- Due to CTIA's commercial expansion plans, using solar energy for electricity consumption is spatially not advisable and the high baseload will make energy storage a very costly endeavour. - Incinerating dry waste may not be as feasible as a fuel source due to its variability in calorific value and carbon emissions.
Two	1. Using the natural gas trigeneration plant or using the anaerobic digestion plant from phase one to supply the critical load of the airport and for additional electrical loads. 2. New infrastructure to adopt a green star rating targeting carbon neutrality in electricity consumption. 3. Smart electrical grid to be adopted to coordinate energy sources ensuring an uninterrupted power supply.	1. Confirmation of availability of additional natural gas to supply the airport's critical electrical load, space constraints for plant operation, suitability to support airport critical electrical load, integration requirements, economic feasibility. 2. Consider the feasibility of incorporating renewable energy such as solar PV and solar thermal for new infrastructure. 3. In-depth investigation into the airport's real time energy consumption to determine energy storage requirements, load-levelling and load shifting techniques for implementation as well as load curtailment to ensure a feasible electrical integration and smart grid design.	- Adoption of other energy sources such as decentralised packaged waste to energy plants or rooftop solar PV plants serving a specific new infrastructure must take into account the operational and maintenance cost of these plants including the environmental impact.
Three	1. Fuel change from natural gas to a fuel with a lower carbon footprint such as LPG or biogas.	1. Investigation into possible alternative fuels that are less carbon intense than natural gas and selecting the	- Technology change might not be possible if there is no technology improvements commercially available.

	2. Process innovation to sequester carbon emissions. 3. Technology change towards no carbon emissions. 4. Carbon offsetting plants or purchasing of carbon credits to reach carbon neutrality in electricity consumption.	combustion engine technology that allows multiple fuel type intake, is key for this to work cost effectively. 2. Sequestering carbon will require in-depth environmental and financial investigation, 3. Technology change will be dependent on the commercial market evolution, and this must be actively monitored. 4. A feasibility study must be undertaken on carbon offsetting plants versus purchasing carbon credits. An integrated view must be considered.	- Carbon sequestration might rely on a range of factors, both environmental, site and business related. - The better choice to invest effort in investigation is a dual fuel combustion engine and carbon offsetting plants on vacant land at regional airports as a commercial venture (independent power producer) or undertake a corporate social investment project installing a solar PV or wind plant at a facility and claim the carbon credits.

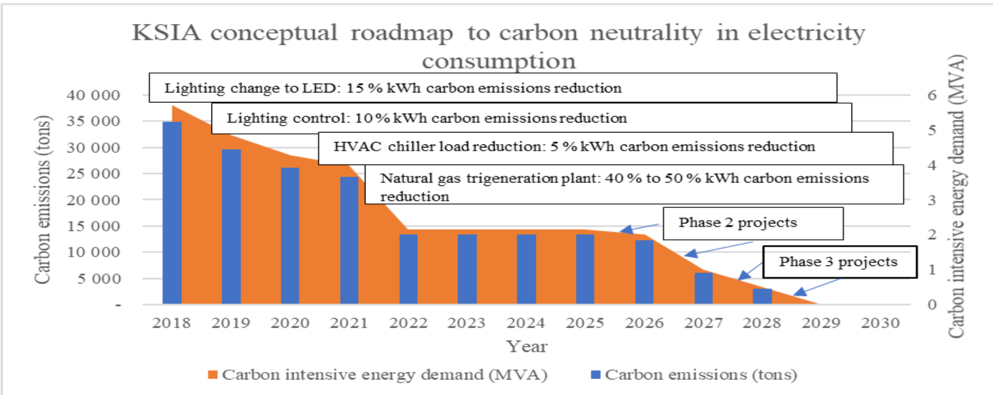


Figure 6: King Shaka International Airport's conceptual roadmap to carbon neutrality in electricity consumption

Table 7: Projects for KSIA's energy mix conceptual roadmap towards carbon neutrality in electricity consumption

Phase	Energy sources and projects	Requirements prior to implementation	Notes
Preliminary	1. Lighting change to LED. 2. Lighting control: occupancy sensors, BMS (building management system) control, dimming functions. 3. HVAC chiller load reduction: convective boundaries - double glazing or low emissivity glass, thermal deflection innovation (heat deflective paint on roof/insulation), wind lobbies, etc. 4. Geyser sleeve technology [Too small to count as a step change on graph].	Financial feasibility and technical assessment (technoeconomic studies)	Wind lobbies were not ideal for KSIA's terminal building layout, so this was not taken to the financial feasibility stage.
One	1. Natural gas trigeneration plants producing electricity	1. Technoeconomic assessment is required as well as a	- Due to KSIA's commercial expansion plans, using solar

	through combustion of natural gas and recovering the waste heat for thermal energy uses such as hot water and powering absorption chillers. 2. Waste to energy via anaerobic digestion producing a biogas that can be combusted for electricity generation	confirmed feasibility based on the engineering design before a financial investment decision is made and security of fuel gas supply. 2. Waste streams are to be tested for their calorific value and a full technoeconomic assessment should follow.	energy for electricity consumption is spatially not advisable and the high baseload will make energy storage a very costly endeavour. - Incinerating dry waste may not be as feasible for a fuel source due to its variability in calorific value and carbon emissions. - Using geothermal energy as a heat sink has costly preliminary groundwork such as soil testing. It is better to undertake a pilot plant at a better suited airport prior to investment for a feasibility study.
Two	1. Using the natural gas trigeneration plant or using the anaerobic digestion plant from phase one to supply the critical load of the airport and for additional electrical loads. 2. New infrastructure to adopt a green star rating targeting carbon neutrality in electricity consumption. 3. Smart electrical grid to be adopted to coordinate energy sources ensuring an uninterrupted power supply	1. Confirmation of availability of additional natural gas to supply the airport's critical electrical load, space constraints for plant operation, suitability to support airport critical electrical load, integration requirements, economic feasibility. 2. Consider the feasibility of incorporating renewable energy such as solar PV and solar thermal for new infrastructure. 3. In-depth investigation into the airport's real time energy consumption to determine energy storage requirements, load-levelling and load shifting techniques for implementation as well as load curtailment to ensure a feasible electrical integration and smart grid design.	- Adoption of other energy sources such as decentralised packaged waste to energy plants or rooftop solar PV plants serving a specific new infrastructure must take into account the operational and maintenance cost of these plants including the environmental impact.
Three	1. Fuel change from natural gas to a fuel with lower carbon footprint such as LPG or biogas. 2. Process innovation to sequester carbon emissions. 3. Technology change towards no carbon emissions. 4. Carbon offsetting plants or purchasing of carbon credits to reach carbon neutrality in electricity consumption.	1. Investigation into possible alternative fuels that are less carbon intense than natural gas and selecting the combustion engine technology that allows multiple fuel type intake is key for this to work cost effectively. 2. Sequestering carbon will require in-depth environmental and financial investigation. 3. Technology change will be dependent on the commercial market	- Technology change might not be possible if there are no technology improvements commercially available. - Carbon sequestration might rely on a range of factors, both environmental, site and business related. - The better choice to invest effort in investigation are dual fuel combustion engine and carbon offsetting plants on vacant land at regional airports as a commercial venture (independent power producer) or undertake a corporate social

		evolution, and this must be actively monitored. 4. A feasibility study must be conducted on carbon offsetting plants versus purchasing carbon credits. An integrated view must be considered.	investment project installing a solar PV or wind plant at a facility and claim the carbon credits.

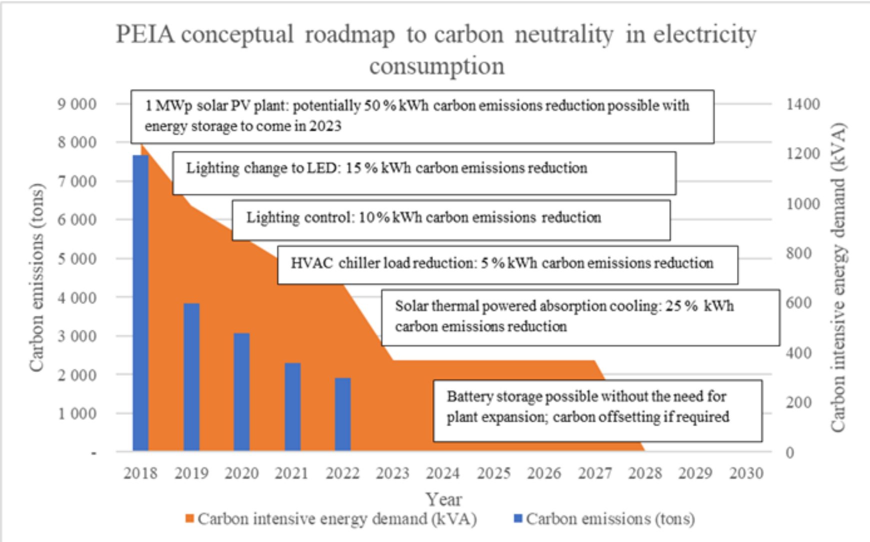


Figure 7: Port Elizabeth International Airport's conceptual roadmap to carbon neutrality in electricity consumption

Table 8: Projects for PEIA's energy mix conceptual roadmap towards carbon neutrality in electricity consumption

Phase	Energy sources and projects	Requirements prior to implementation	Notes
Preliminary	1. Lighting change to LED. 2. Lighting control: occupancy sensors, BMS (building management system) control, dimming functions. 3. HVAC chiller load reduction: convective boundaries - double glazing or low emissivity glass, thermal deflection innovation (heat deflective paint on roof/insulation), wind lobbies, etc. 4. Geyser sleeve technology [Too small to count as a step change on graph].	Financial feasibility and technical assessment (technoeconomic studies).	Wind lobbies were not ideal for PEIA's terminal building layout so this was not taken to the financial feasibility stage.
One	1. Solar PV plant for electricity generation. 2. Solar thermal plant for powering absorption chillers to satisfy air conditioning requirements. 3. Wind energy generating	1. 1 MWp solar PV plant is being installed, ensure that the solar PV yield is prioritised to be used first before grid electricity in the grid tied connection. 2. A financial viability study must be undertaken for a solar thermal	- There are insufficient volumes of waste for energy generation. - Using geothermal energy as a heat

	electricity via vertical axis wind turbines.	powered absorption chilling plant. 3. Securing of a suitable installation site with the necessary approvals from Air Traffic Navigational Services (ATNS) and South African Civil Aviation Authority (SACAA), followed by a full technoeconomic assessment.	sink has costly preliminary groundwork such as soil testing. It is better to undertake a pilot plant at a better suited airport prior to investment for a feasibility study.
Two	1. Adequate battery storage for the airport's use after sunset. 2. New infrastructure to adopt a green star rating targeting carbon neutrality in electricity consumption. 3. Smart electrical grid to be adopted to coordinate energy sources ensuring an uninterrupted power supply.	1. Battery storage must be investigated and a technoeconomic assessment undertaken to select the best technology suited for the installation. 2. Consider the feasibility of incorporating renewable energy such as solar PV and solar thermal for new infrastructure. 3. In-depth investigation into the airport's real time energy consumption to determine energy storage requirements, load-levelling and load shifting techniques for implementation, as well as load curtailment, to ensure a feasible electrical integration and smart grid design.	- Adoption of other energy sources such as rooftop solar PV plants or solar thermal plants serving a specific new infrastructure must take into account the operational and maintenance cost of these plants including the environmental impact.
Three	1. Carbon offsetting plants or purchasing of carbon credits to reach carbon neutrality in electricity consumption.	1. A feasibility study must be conducted on carbon offsetting plants versus purchasing carbon credits. An integrated view must be considered.	- It could be best to increase capacity on existing solar PV or wind plants and sell excess kWhs produced.

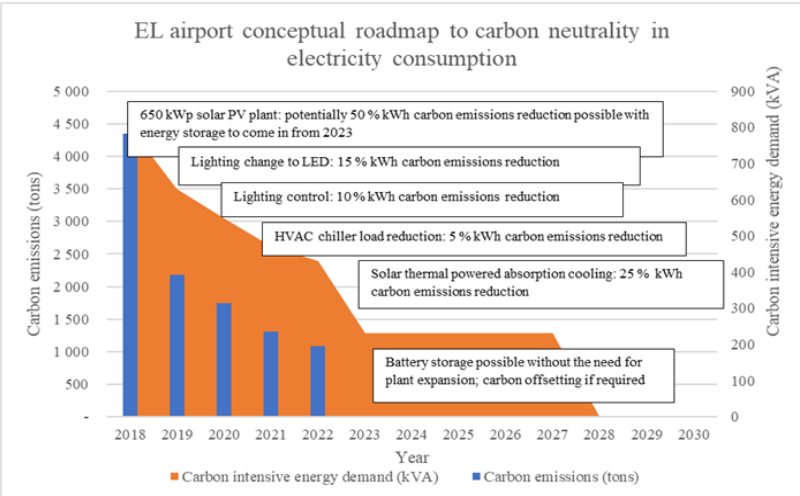


Figure 8: East London Airport's conceptual roadmap to carbon neutrality in electricity consumption

Table 9: Projects for EL airport's energy mix conceptual roadmap towards carbon neutrality in electricity consumption

Phase	Energy sources and projects	Requirements prior to implementation	Notes
Preliminary	1. Lighting change to LED. 2. Lighting control: occupancy sensors, BMS (building management system) control, dimming functions. 3. HVAC chiller load reduction: convective boundaries - double glazing or low emissivity glass, thermal deflection innovation (heat deflective paint on roof/insulation), wind lobbies, etc. 4. Geyser sleeve technology [Too small to count as a step change on graph].	Financial feasibility and technical assessment (technoeconomic studies).	Wind lobbies were not ideal for EL airport's terminal building layout, so this was not taken to the financial feasibility stage.
One	1. Solar PV plant for electricity generation. 2. Solar thermal plant for powering absorption chillers to satisfy air conditioning requirements. 3. Wind energy generating electricity via vertical axis wind turbines.	1. 650 kWp solar PV plant is being installed, ensure that the solar PV yield is prioritised to be used first before grid electricity in the grid tied connection. 2. A financial viability study must be undertaken for a solar thermal powered absorption chilling plant. 3. Securing of a suitable installation site with the necessary approvals from Air Traffic Navigational Services (ATNS) and South African Civil Aviation Authority (SACAA), followed by a full technoeconomic assessment.	- There are insufficient volumes of waste for energy generation. - Using geothermal energy as a heat sink has costly preliminary groundwork such as soil testing must be undertaken, it is better to undertake a pilot plant at a better suited airport prior to investment for a feasibility study.
Two	1. Adequate battery storage for the airport's use after sunset. 2. New infrastructure to adopt a green star rating targeting carbon neutrality in electricity consumption. 3. Smart electrical grid to be adopted to coordinate energy sources ensuring an uninterrupted power supply.	1. Battery storage must be investigated and a technoeconomic assessment undertaken to select the best technology suited for the installation. 2. Consider the feasibility of incorporating renewable energy such as solar PV and solar thermal for new infrastructure. 3. In-depth investigation into the airport's real time energy consumption to determine energy storage requirements, load-levelling and load shifting techniques for implementation as well as load curtailment to ensure a feasible electrical integration and smart grid design.	- Adoption of other energy sources such as rooftop solar PV plants or solar thermal plants serving a specific new infrastructure must take into account the operational and maintenance cost of these plants including the environmental impact.
Three	1. Carbon offsetting plants or purchasing of carbon credits to	1. A feasibility study must be conducted on carbon offsetting	- It could be best to increase capacity on

	reach carbon neutrality in electricity consumption.	plants versus purchasing carbon credits. An integrated view must be considered.	existing solar PV or wind plants and sell excess kWhs produced.

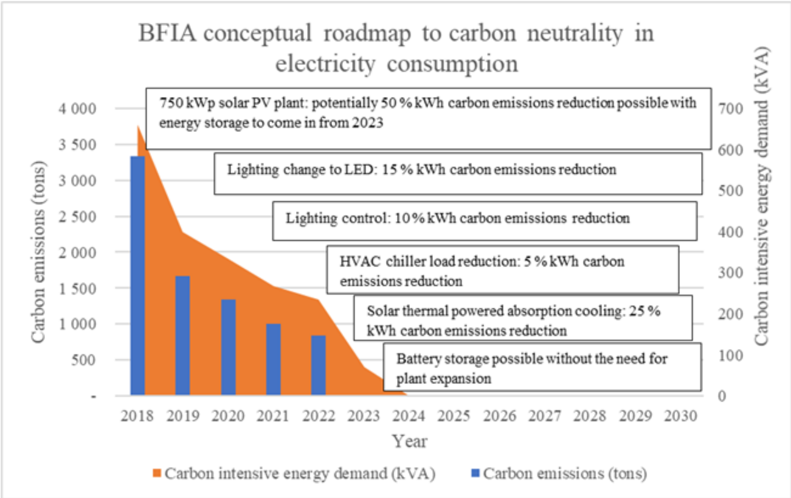


Figure 9: Bram Fischer International Airport's Conceptual roadmap to carbon neutrality in electricity consumption

Table 10: Projects for BFIA's energy mix conceptual roadmap towards carbon neutrality in electricity consumption

Phase	Energy sources and projects	Requirements prior to implementation	Notes
Preliminary	1. Lighting change to LED. 2. Lighting control: occupancy sensors, BMS (building management system) control, dimming functions 3. HVAC chiller load reduction: convective boundaries - double glazing or low emissivity glass, thermal deflection innovation (heat deflective paint on roof/insulation), wind lobbies, etc. 4. Geyser sleeve technology [Too small to count as a step change on the graph].	Financial feasibility and technical assessment (technoeconomic studies).	Wind lobbies were not ideal for BFIA's terminal building layout, so this was not taken to the financial feasibility stage.
One	1. Solar PV plant for electricity generation. 2. Solar thermal plant for powering absorption chillers to satisfy air conditioning requirements.	1. 750 kWp solar PV plant is being installed, ensure that the solar PV yield is prioritised to be used first before grid electricity in the grid tied connection. 2. A financial viability study must be undertaken for a solar thermal powered absorption chilling plant.	- There are insufficient volumes of waste for energy generation. - Using geothermal energy as a heat sink has costly preliminary groundwork such as soil testing. It is better to undertake a pilot plant at a better suited airport prior to investment for a feasibility study.

Two	1. Adequate battery storage for the airport's use after sunset. 2. New infrastructure to adopt a green star rating targeting carbon neutrality in electricity consumption. 3. Smart electrical grid to be adopted to coordinate energy sources ensuring an uninterrupted power supply.	1. Battery storage must be investigated and a technoeconomic assessment undertaken to select the best technology suited for the installation. 2. Consider the feasibility of incorporating renewable energy such as solar PV and solar thermal for new infrastructure. 3. In-depth investigation into the airport's real time energy consumption to determine energy storage requirements, load-levelling and load shifting techniques for implementation as well as load curtailment to ensure a feasible electrical integration and smart grid design.	- Adoption of other energy sources such as rooftop solar PV plants or solar thermal plants serving a specific new infrastructure must take into account the operational and maintenance cost of these plants including the environmental impact.
Three	1. Carbon offsetting plants or purchasing of carbon credits to reach carbon neutrality in electricity consumption.	1. A feasibility study must be conducted on carbon offsetting plants versus purchasing carbon credits. An integrated view must be considered.	- It could be best to increase capacity on existing solar PV or wind plants and sell excess kWhs produced.

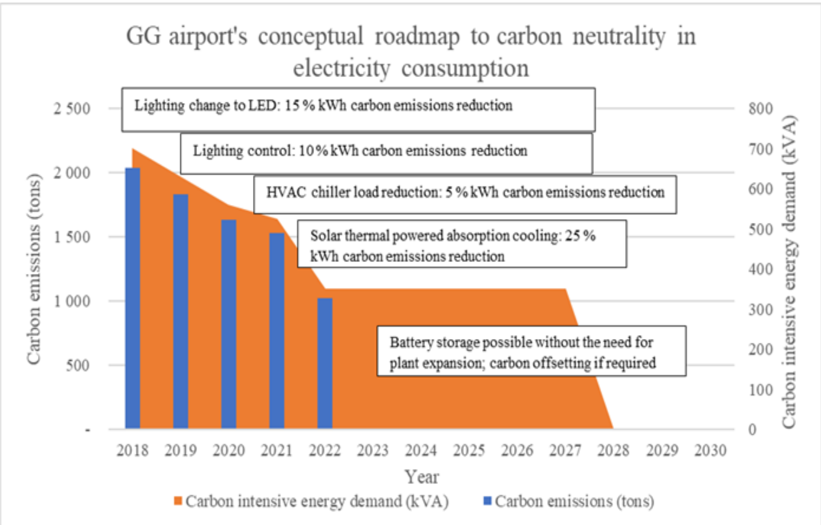


Figure 10: George Airport's conceptual roadmap to carbon neutrality in electricity consumption

Table 11: Projects for GG airport's energy mix conceptual roadmap towards carbon neutrality in electricity consumption

Phase	Energy sources and projects	Requirements prior to implementation	Notes
Preliminary	1. Lighting change to LED. 2. Lighting control: occupancy sensors, BMS (building management system) control, dimming functions. 3. HVAC chiller load reduction: convective boundaries - double glazing or low emissivity glass, thermal deflection innovation (heat deflective paint on roof/insulation), wind lobbies, etc. 4. Geyser sleeve technology [Too small to count as a step change on graph].	Financial feasibility and technical assessment (technoeconomic studies).	Wind lobbies were not ideal for GG airport's terminal building layout, so this was not taken to the financial feasibility stage.
One	1. Solar PV plant for electricity generation. 2. Solar thermal plant for powering absorption chillers to satisfy air conditioning requirements. 3. Wind energy generating electricity via vertical axis wind turbines.	1. 750 kWp solar PV plant has been installed, ensure that the solar PV yield is prioritised to be used first before grid electricity in the grid tied connection and investigate expansion of capacity. 2. A financial viability study must be undertaken for a solar thermal powered absorption chilling plant. 3. Securing of a suitable installation site with the necessary approvals from Air Traffic Navigational Services (ATNS) and South African Civil Aviation Authority (SACAA), followed by a full technoeconomic assessment.	- There are insufficient volumes of waste for energy generation. - Using geothermal energy as a heat sink has costly preliminary groundwork such as soil testing, it is better to undertake a pilot plant at a better suited airport prior to investment for a feasibility study.
Two	1. Adequate battery storage for the airport's use after sunset. 2. New infrastructure to adopt a green star rating targeting carbon neutrality in electricity consumption. 3. Smart electrical grid to be adopted to coordinate energy sources ensuring an uninterrupted power supply.	1. Battery storage must be investigated and a technoeconomic assessment undertaken to select the best technology suited for the installation. 2. Consider the feasibility of incorporating renewable energy such as solar PV and solar thermal for new infrastructure. 3. In-depth investigation into the airport's real time energy consumption to determine energy storage requirements, load-levelling and load shifting techniques for implementation, as well as load curtailment, to ensure a feasible electrical integration and smart grid design.	- Adoption of other energy sources such as rooftop solar PV plants or solar thermal plants serving a specific new infrastructure must take into account the operational and maintenance cost of these plants including the environmental impact.
Three	1. Carbon offsetting plants or purchasing of carbon credits to reach carbon	1. A feasibility study must be conducted on carbon offsetting plants versus purchasing carbon credits. An	- It could be best to increase capacity on existing solar

	neutrality in electricity consumption.	integrated view must be considered.	PV or wind plants and sell excess kWhs produced.

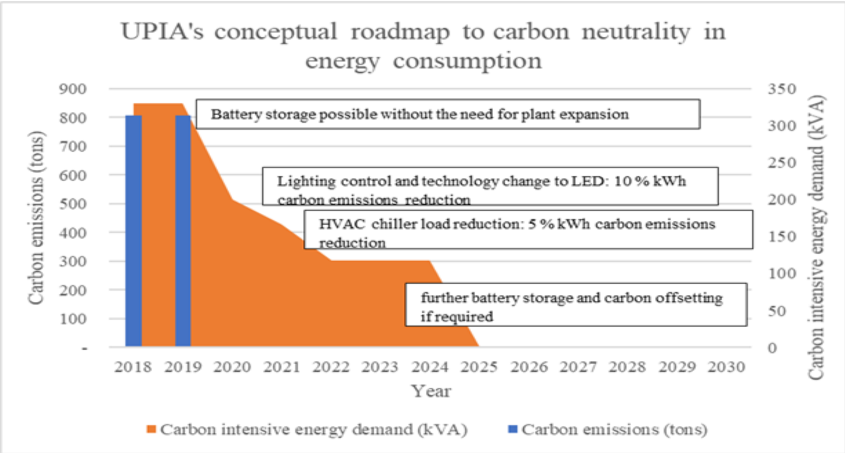


Figure 11: Upington Airport's conceptual roadmap to carbon neutrality in electricity consumption

Table 12: Projects for UPIA's energy mix conceptual roadmap towards carbon neutrality in electricity consumption

Phase	Energy sources and projects	Requirements prior to implementation	Notes
Preliminary	1. Lighting change to LED. 2. Lighting control: occupancy sensors, BMS (building management system) control, dimming functions. 3. HVAC chiller load reduction: convective boundaries - double glazing or low emissivity glass, thermal deflection innovation (heat deflective paint on roof/insulation), wind lobbies, etc. 4. Geyser sleeve technology [Too small to count as a step change on graph].	Financial feasibility and technical assessment (technoeconomic studies)	Wind lobbies were not ideal for UPIA's terminal building layout, so this was not taken to the financial feasibility stage.
One	1. Solar PV plant for electricity generation.	1. 500 kWp solar PV plant has been installed, ensure that the solar PV yield is prioritised to be used first before grid electricity in the grid tied connection.	- It is possible that the solar PV plant installed can provide for the airport's full energy requirements.
Two	1. Adequate battery storage for the airport's use after sunset. 2. New infrastructure to adopt a green star rating targeting carbon neutrality in electricity	1. Battery storage must be investigated and a technoeconomic assessment undertaken to select the best technology suited for the installation. 2. Consider the feasibility of incorporating renewable energy such as solar PV and solar thermal for new	- Adoption of other energy sources such as rooftop solar PV plants or solar thermal plants serving a specific new infrastructure

	consumption. 3. Smart electrical grid to be adopted to coordinate energy sources ensuring an uninterrupted power supply.	infrastructure. 3. In-depth investigation into the airport's real time energy consumption to determine energy storage requirements, load-levelling and load shifting techniques for implementation, as well as load curtailment, to ensure a feasible electrical integration and smart grid design.	must take into account the operational and maintenance cost of these plants including the environmental impact.
Three	1. Carbon offsetting plants or purchasing of carbon credits to reach carbon neutrality in electricity consumption.	1. A feasibility study must be conducted on carbon offsetting plants versus purchasing carbon credits. An integrated view must be considered.	- It could be best to increase capacity on existing solar PV plant and sell excess kWhs produced.

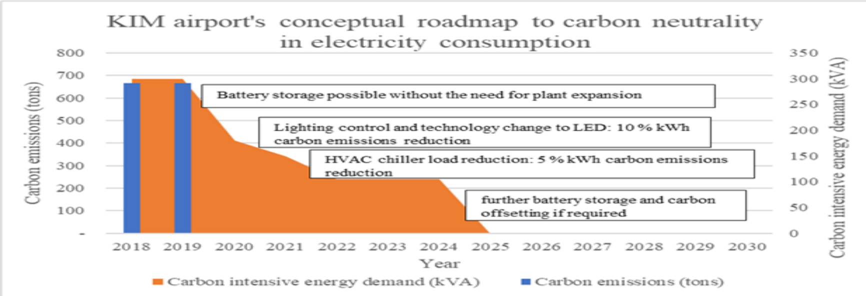


Figure 12: Kimberley Airport's conceptual roadmap to carbon neutrality in electricity consumption

Table 13: Projects for UPIA's energy mix conceptual roadmap towards carbon neutrality in electricity consumption

Phase	Energy sources and projects	Requirements prior to implementation	Notes
Preliminary	1. Lighting change to LED. 2. Lighting control: occupancy sensors, BMS (building management system) control, dimming functions. 3. HVAC chiller load reduction: convective boundaries - double glazing or low emissivity glass, thermal deflection innovation (heat deflective paint on roof/insulation), wind lobbies, etc. 4. Geyser sleeve technology [Too small to count as a step change on the graph].	Financial feasibility and technical assessment (technoeconomic studies).	Wind lobbies were not ideal for UPIA's terminal building layout; hence it was not taken to the financial feasibility stage.
One	1. Solar PV plant for electricity generation.	1. 500 kWp solar PV plant has been installed, ensure that the solar PV yield is prioritised to be used first before grid electricity in the grid tied connection.	- It is possible that the solar PV plant installed can provide for the airport's full energy requirements.
Two	1. Adequate battery storage for the airport's use after	1. Battery storage must be investigated and a technoeconomic assessment	- Adoption of other energy sources

	sunset. 2. New infrastructure to adopt a green star rating targeting carbon neutrality in electricity consumption. 3. Smart electrical grid to be adopted to coordinate energy sources ensuring an uninterrupted power supply.	undertaken to select the best technology suited for the installation. 2. Consider the feasibility of incorporating renewable energy such as solar PV and solar thermal for new infrastructure. 3. In-depth investigation into the airport's real time energy consumption to determine energy storage requirements, load-levelling and load shifting techniques for implementation, as well as load curtailment, to ensure a feasible electrical integration and smart grid design	such as rooftop solar PV plants or solar thermal plants serving a specific new infrastructure must take into account the operational and maintenance cost of these plants including the environmental impact.
Three	1. Carbon offsetting plants or purchasing of carbon credits to reach to carbon neutrality in electricity consumption	1. A feasibility study must be conducted on carbon offsetting plants versus purchasing carbon credits. An integrated view must be considered.	- It could be best to increase capacity on existing solar PV plant and sell excess kWhs produced.

The conceptual roadmaps to carbon neutrality are the fulfilment of the FEL 1 or front end loading Stage 1 that follows an approved strategy. It can be seen that the conceptual plans to carbon neutrality by 2030 give approximations of carbon emissions reduction for each intervention, however, this has to be confirmed through further investigation. Where the specific intervention does not apply at an airport, or is not technically suitable upon initial enquiry, it will not follow into the technoeconomic assessment route. Some technologies such as LED lighting and lighting control do not need a full technical assessment as they are widely used and familiar technologies. However, where a certain technology is not very well known or proven in South Africa, a full technoeconomic assessment must follow and, in some cases, a preliminary design is required especially where there is high risk and high investment.

The following technologies will be investigated at FEL 2 level which is pre-feasibility for the confirmation of the roadmaps to carbon neutrality:

- LED lighting
- Lighting control
- HVAC energy reduction techniques
- Geyser sleeve technology
- Solar thermal deflection innovation (or heat deflective coating)
- Convective boundaries (double glazing or low emissivity glass)
- Green buildings for new and existing infrastructure
- Solar PV plants
- Solar thermal absorption cooling
- Geothermal heat sinks

- Wind energy with vertical axis wind turbines
- Natural gas trigeneration plants
- Anaerobic digestion

Their applicability to the airports has been highlighted to satisfy the energy demand of the airports. The next step will be to perform the technical and economic assessments. Feasible projects will be used in the confirmed roadmap to carbon neutrality; however, the airports have a business prerogative to certify existing terminal buildings with a 4-, 5- or 6-star green rating, regardless of feasibility as the related operational and public relations benefits far outweigh the capital outlay.

CONCLUSIONS

This paper presented the conceptual roadmaps to carbon neutrality in electricity consumption for all nine airports in South Africa according to the strategic environmental objective of the organisation to reduce its carbon footprint. It also followed the principles of energy security while on the journey to conceptualisation of the roadmaps to carbon neutrality by 2030. The work that follows to confirm these roadmaps to carbon neutrality by 2030 will be technical and economic assessments with confirmed carbon footprint reduction impact for each of the identified technologies, namely LED lighting, LED lighting control, HVAC energy reduction techniques, geyser sleeve technology, solar thermal deflection innovation (or heat deflective coating), convective boundaries (or double glazing/low emissivity glass), green buildings, solar PV plants, solar thermal absorption cooling, geothermal heat sinks, wind energy with vertical axis wind turbines, natural gas trigeneration plants and anaerobic digestion.

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